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(54) Improved eyepiece design.

(57) An improved eyepiece for an optical system. In general, the inventive eyepiece (10) includes a refractive element (16) and an optical arrangement for relaying the entrance pupil of the system to the refractive element. In a specific implementation, the optical arrangement includes a concave primary mirror (12) and a secondary mirror (14). The mirrors are mounted to communicate an image from the refractive element (16) to the entrance pupil (40). In the specific implementation, the refractive element (16) is one or more refractive lenses. The use of a reflective optical arrangement allows for the long eye relief. The placement of the entrance pupil close to the pupil of the lens allows for the use of a compact optical arrangement with high ratio of eye relief to effective focal length with a compact optical arrangement. The system affords minimal lateral chromatic aberration and good image quality.

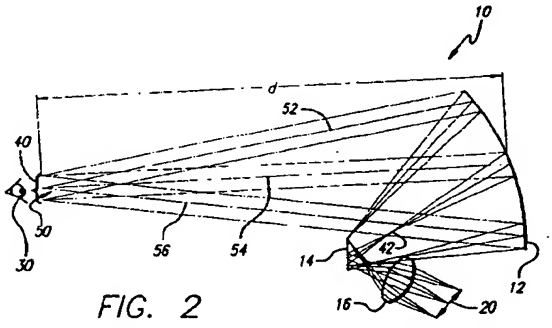

FIG. 2

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BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention relates to optics. More specifically, the present invention relates to eyepieces for optical instruments.

While the present invention is described herein with reference to illustrative embodiments for particular applications, it should be understood that the invention is not limited thereto. Those having ordinary skill in the art and access to the teachings provided herein will recognize additional modifications, applications, and embodiments within the scope thereof and additional fields in which the present invention would be of significant utility.

Description of the Related Art:

Many optical systems including microscopes, telescopes, binoculars and the like, include an eyepiece into which the user peers to observe an image provided by the system. The conventional eyepiece, such as that disclosed in U. S. Patent No. 2,423,676, entitled EYEPIECE, issued July 8, 1947 to Fred E. Altman is typically constructed with an arrangement of refractive optical elements or lenses.

Eye relief is an important consideration in the design of an optical system. Eye relief is the distance between the iris of the eye of the observer and the first surface of the first lens of the system.

For reasons of safety and convenience, a long eye relief is desirable. In weapons systems, for example, an optical instrument may be utilized as a sighting mechanism. For certain weapons such as rocket and missile launchers, long eye relief is desired to prevent injury to the user due to any recoil of the weapon when the weapon is fired. In microscopes, long eye relief allows the user to view the sample under examination from a convenient distance causing less effort, eye strain and stress. However, there are several countervailing considerations which prevent the designer from optimizing the system on the basis of eye relief alone.

The first is the general requirement that the field-of-view of the eyepiece equal the field-of-view of the user. With the typical focusing lenses of the conventional refractive eyepiece, when the observer's eye is at the pupil position, the observer will see the entire image located at the eyepiece image plane. As the observer moves his eye longitudinally away from the eyepiece, the outer portion of the field-of-view will first be vignetted and then finally disappear. Therefore, the sizes of the lenses have to increase almost linearly with respect to the longitudinal eye displacement or eye relief in order to maintain the same field-of-view. Unfortunately, the edge thickness of a focusing lens approaches zero very quickly. Therefore, a thickening each lens is necessary to accommodate longer eye relief. However, because of the quadratic relationship between the size of the lens and thickness thereof due to curvature, thickness increases rapidly with size. Accordingly, larger lenses are generally much thicker, heavier and more costly and the image quality therethrough is much generally lower than the lenses required in instruments with smaller eye relief. In general, when the ratio of eye relief to effective focal length (EREFL) is less than one, good image quality is easily obtainable. However, when the EREFL exceeds unity, good image quality is difficult to achieve and the eyepiece becomes impracticably bulky.

In addition, conventional refractive eyepieces suffer from poor image quality due to severe chromatic aberration, large field curvature and chromatic aberration.

Thus, there is an ongoing need in the art for a low cost, light weight system design which offers long eye relief and good image quality.

SUMMARY OF THE INVENTION

The need in the art is addressed by the present invention which provides an improved eyepiece for an optical system. In general, the inventive eyepiece includes a refractive element and an optical arrangement for relaying the entrance pupil of the system to the refractive element. In a specific implementation, the optical arrangement includes a concave primary mirror and a secondary mirror. The mirrors are mounted to communicate an image from the refractive element to the entrance pupil. In the specific implementation, the refractive element is one or more refractive lenses.

The use of a reflective optical arrangement allows for the long eye relief. The placement of the entrance pupil close to the lens allows for the use of a compact optical arrangement with high ratio of eye relief to effective focal length with a compact optical arrangement. The system affords minimal chromatic distortion and good image quality.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of an eyepiece constructed in accordance with conventional teachings.

Fig. 2 is a diagram of an eyepiece constructed in accordance with the teachings of the present invention.

DESCRIPTION OF THE INVENTION

Illustrative embodiments and exemplary applications will now be described with reference to the accompanying drawings to disclose the advantageous teachings of the present invention.

Fig. 1 is a diagram of a conventional eyepiec . The eyepiece 10' includes a first cemented doubl t 12', a singlet 14' and a second cemented doublet 16'. The first cemented doublet comprises a plano-concave negative power lens and a double-convex positive power lens, with the first, second and third surfaces 18', 20' and 22', respectively. The singlet 14' has positive optical power with the first and second surfaces 24' and 26', respectively. The second cemented doublet comprises a double-convex positive power lens and a double-concave negative power lens with the first, second and third surfaces 28', 30' and 32', respectively. To balance the chromatic aberrations, the positive power lenses and the negative power lenses would generally be constructed with crown glasses (having low dispersion characteristics) and flint glasses (having high dispersion characteristics), respectively. The result is a bulky optical arrangement with short eye relief 'd' vis-a-vis the eye 30' of an observer.

As mentioned above, the ratio of eye relief to effective focal length of the eyepiece 10' of Fig. 1 can be expected to be less than one. Increases in eye relief in accordance with conventional teachings are afforded with compromise of system performance, size, weight and cost.

The present invention addresses the need in the art for an eyepiece design which offers long eye relief at low cost, size and weight with good image quality.

An eyepiece constructed in accordance with the present teachings is illustrated in Fig. 2. The eyepiece 10 includes a primary mirror 12, a secondary mirror 14 and a refractive lens 16. The primary mirror 12 is concave. The secondary mirror 14 may be concave, flat or convex. The reflective surfaces of both mirrors 12 and 14 may be either spherical, aspheric or generalized in shape. The lens 16 may be replaced with a group of refractive elements with at least two different optical materials for chromatic aberration correction. The refractive elements may be spherical or aspheric in shape.

Light from the image plane 20 is relayed by the lens 16, reflected by the secondary mirror 14 to the primary mirror 12 and collimated by the primary mirror on the entrance pupil 40. Although the intermediate image surface 42 is disposed between the primary mirror and the secondary mirror, it may be disposed between the secondary mirror and the lens 16 for some applications.

As discussed below, in the preferred embodiment, the design of system is such that the entrance pupil 40 is relayed to a point between the secondary mirror 14 and the lens 16. This allows for the size of the lens 16 and the secondary mirror 14 to be minimized while affording good image quality by minimizing lateral chromatic aberrations.

The design methodology of the present invention is as follows. First, the desired eye relief is selected. This distanc 'd' is measured as the length of the center ray 54 from the entrance pupil 40 to the primary mirror 12. Next, the field-of-view is selected. The field-of-view is the angle between the top and bottom rays 52 and 56 of the center bundle 50 of rays as shown in Fig. 2. The pupil size 's' is set as the diameter of the entrance pupil 40. The beamwidth, the field of view, helps to set the size of the primary mirror 12. The focal length of the primary mirror 12 is used to determine the spacing thereof and the size and spacing of the secondary mirror 14 in a conventional manner. The radius of curvature, size and shape of the active surfaces of the optical elements would be determined in a conventional manner using a program such as CODEV licensed by Optical Research Associated, Inc.. For the lens 16 or the refractive group, other parameters such as the type and thickness of glass, the merit function would be factored in as well. The program would be commanded to vary the radii of curvature (surface function) of the primary and secondary mirrors and the spacing therebetween the primary mirror and the secondary mirror as well as the spacing between the primary mirror and the refractive element(s) to relay the entrance pupil 40 to the entrance pupil of the lens 16. As mentioned above, this allows for the secondary mirror and the lens to be compact while minimizing chromatic aberrations therein. In some applications, the surface function of the primary and secondary mirrors and some of the lenses can be generalized aspheric surface shapes to obtain better image quality and distortion characteristics.

Thus, the present invention has been described herein with reference to a particular embodiment for a particular application. Those having ordinary skill in the art and access to the present teachings will recognize additional modifications applications and embodiments within the scope thereof. For example, the secondary mirror can be either tilted, decentered or tilted and decentered with respect to the axis of the primary mirror to balance the asymmetric aberration generated by the primary mirror. The refractive lens element(s) can be either tilted, decentered or tilted and decentered with respect to the axis of the primary mirror to further reduce any residual asymmetric aberration. In addition, chromatic aberration may be reduced further with use of a diffractive element, such as a grating, a frenzel lens, or a zone plate, on the surface of the lens or as a stand alone element. See U. S. Patents 5,044, 706, entitled OPTICAL ELEMENT EMPLOYING ASPHERICAL AND BINARY GRATING OPTICAL SURFACES, issued September 3, 1991 to C. W. Chen; 5,148,314, entitled OPTICAL SYSTEMS EMPLOYING REFRACTIVE AND DIFFRACTIVE OPTICAL ELEMENTS TO CORRECT FOR CHROMATIC ABERRATION, issued September 15, 1992, to C. W. Chen; and 5,151,823, entitled BIOCULAR EYEPIECE OPTICAL SYSTEM EM-

PLOYING REFRACTIVE AND DIFFRACTIVE OPTICAL ELEMENTS, issued September 29, 1992, to C. W. Chen, the t achings of which are incorporated herein by r ference.

It is therefore intended by the appended claims to cover any and all such applications, modifications and embodiments within the scope of the present invention.

Claims

1. An improved eyepiece for an optical system having a entrance pupil, said eyepiece comprising:
   a refractive element and
   reflective means for relaying said entrance pupil to said refractive element.

2. The invention of Claim 1 wherein said reflective means includes a first mirror mounted to communicate an image from said refractive element to said entrance pupil.

3. The invention of Claim 2 wherein said reflective means further includes a second mirror for communicating said image from said refractive element to said first mirror.

4. The invention of Claim 3 wherein said first mirror is concave.

5. The invention of Claim 4 wherein the entrance pupil of the system is relayed to a position between the refractive element and the second mirror.

6. The invention of Claim 1 wherein said refractive element is a lens.

7. In an optical system having an eyepiece with a refractive element therein and an input aperture serving as an entrance pupil, an improvement wherein said improvement comprises:
   eye relief means for relaying said entrance pupil to said refractive element, said eye relief means including:
   a first reflective element for communicating an image from said refractive element to said entrance pupil and
   a second reflective element for communicating said image from said refractive element to said first reflective element.

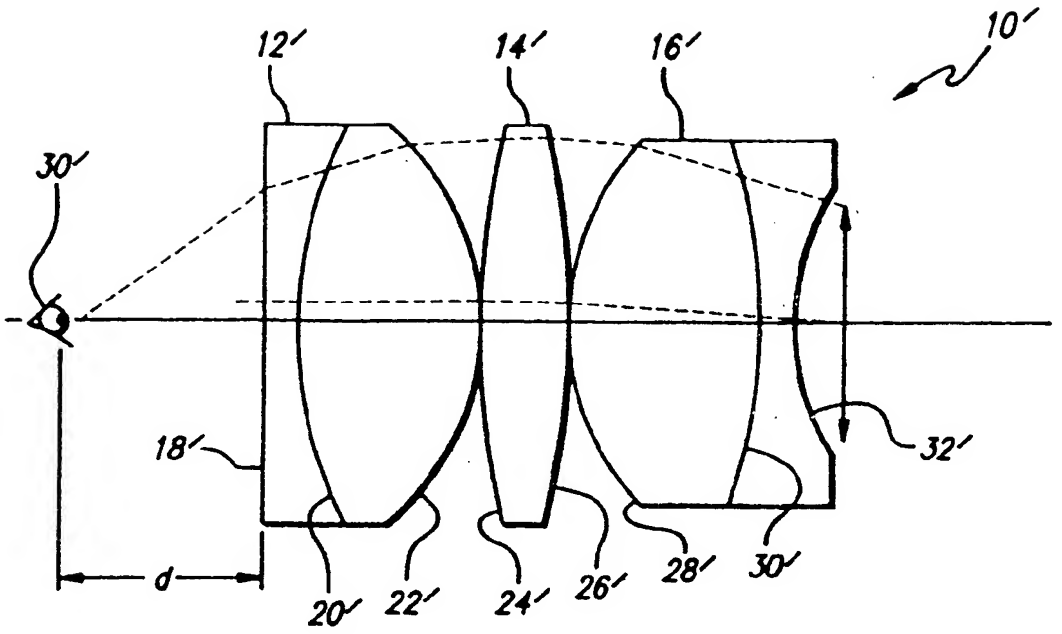

FIG. 1

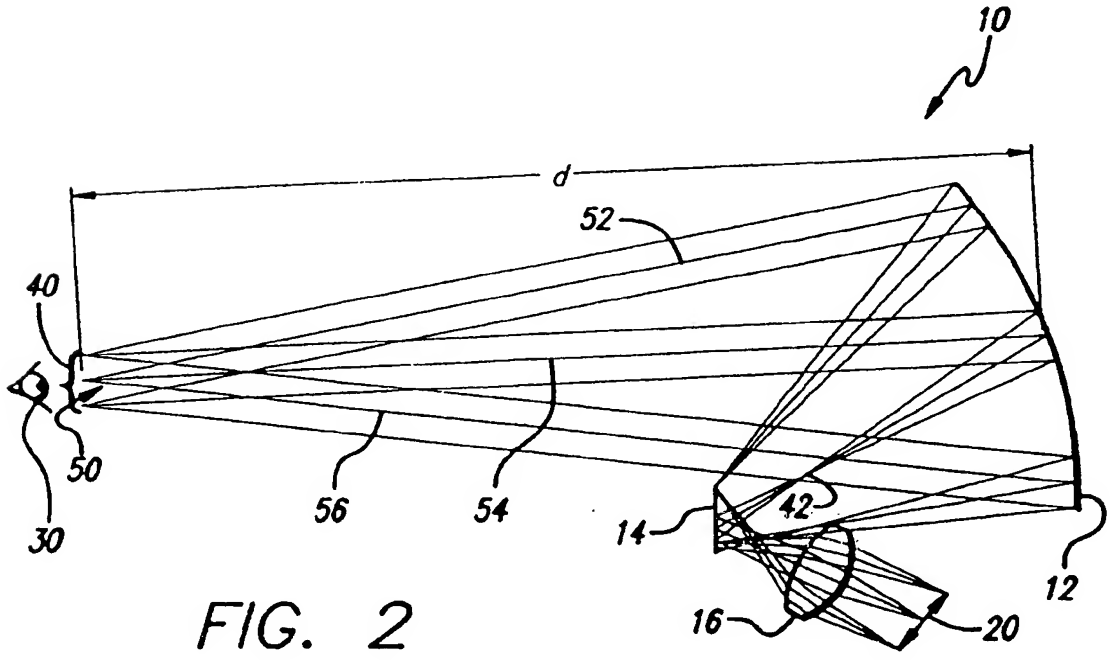

FIG. 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 30 8571

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X A	GB-A-2 182 160 (TRT) * the whole document * ---	1,2,4,6 3,7	G02B25/00 G02B17/08
A	JP-A-5 303 055 (OLYMPUS) * abstract; figures * ---	1,2,4,6, 7	
A	FR-A-1 342 064 (CARL ZEISS JENA) * the whole document * ---	1-4,7	
D,A	US-A-2 423 676 (ALTMAN) * the whole document * -----	1,7	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

G02B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	14 February 1995	Ward, S

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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